The NASA Ames Hypervelocity Free Flight Aerodynamic Facility for Experimental Simulation of the Atmospheric Break-Up of Meteors

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BACKGROUND

NASA Ames Research Center is developing tools for reliably assessing the impact damage that Potentially Hazardous Asteroids could inflict on the Earth. One task of this activity is to develop physics-based simulations of meteor entry and breakup in order to improve risk assessment tools. The modeling approach leverages experience in aerothermodynamics and thermal protection system design for re-entry spacecraft, with current aerothermal environment simulation tools being modified to treat shock layer temperatures and stagnation pressures up to those of interest for 20 km/s meteor entries (~30,000 K and 300 bar). [1] As in the case of building spacecraft entry systems, well designed ground-based tests are required to validate simulation tools, and help quantify uncertainties in the predictions. The Hypervelocity Free Flight Aerodynamic Facility at NASA Ames Research Center provides a potential platform for the experimental simulation of meteor breakup at conditions that closely match full-scale entry condition for select parameters.

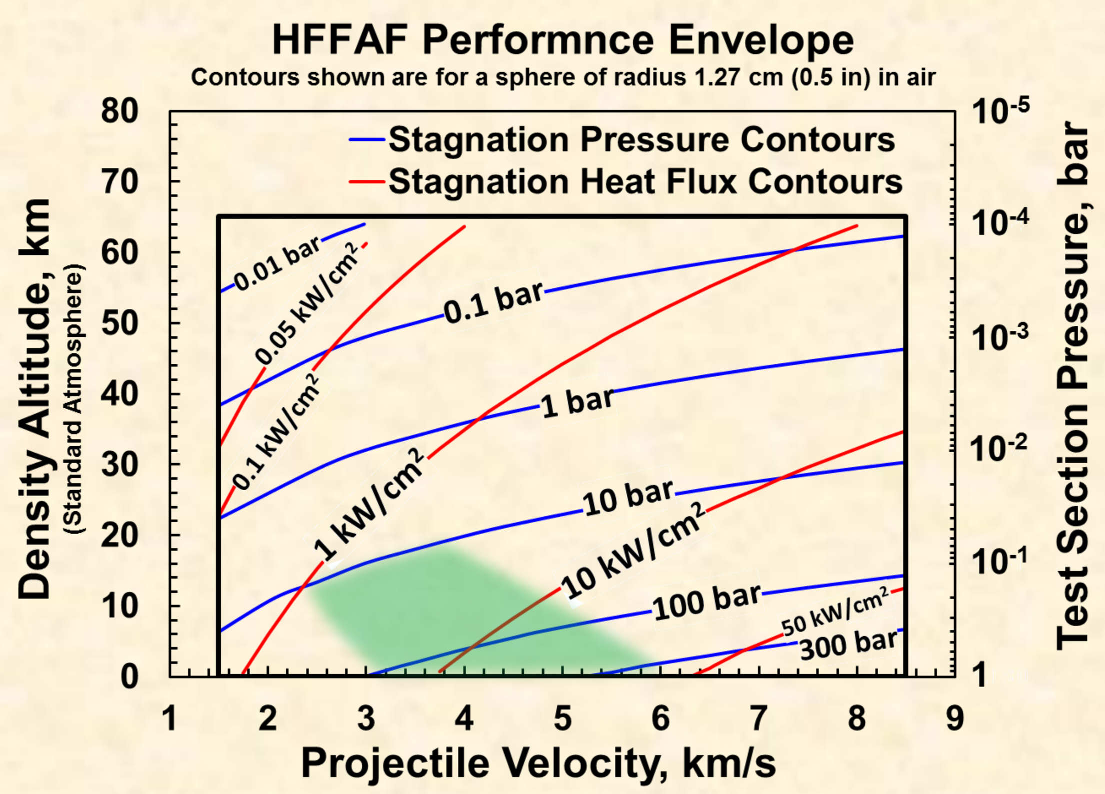
THE HYPERVELOCITY FREE FLIGHT AERODYNAMIC FACILITY (HFFAF)

The HFFAF has a 23 m long, 1 m diameter, controlled-atmosphere test section through which projectiles can be flown at speeds approaching 9 km/s. The test section pressure can be set between 1 bar and ~10^{-4} bar to simulate flight at different altitudes, and practically any test gas may be used.

Although higher velocities cannot be achieved, the extreme stagnation pressures and convective heat-transfer rates of meteor entry can be attained by testing at higher pressures (lower equivalent altitudes). The facility performance envelope (lower right) shows contour lines of stagnation-point pressure (blue) and convective heat flux (red) on a 25 mm diameter sphere in terms of velocity and test section pressure. The shaded region (green) shows the range of test conditions that would match stagnation pressure and convective heat flux expected for spherical meteors ranging from 10 m to 30 m in diameter entering the atmosphere from 12 km/s to 20 km/s. [1]

Testing can be conducted in heavy gases such as Ar, Kr, or Xe in order to achieve full-scale radiative heat flux. Galileo probe models were flown in Xe to produce shock-layer temperatures representative of speeds > 40 km/s and radiative heat flux as high as 1 MW/cm^2. [2]

HFFAF Test Section



Projectile in the HFFAF in flight at 6.8 km/s

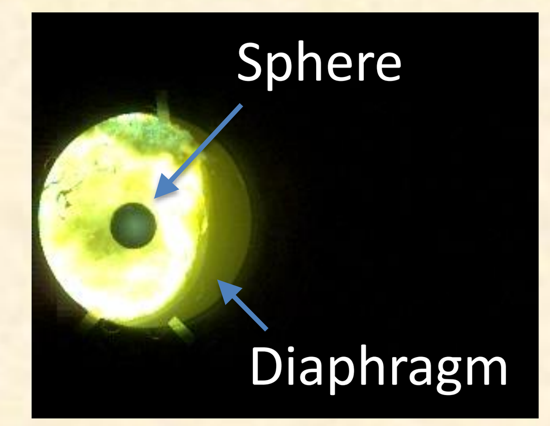
[1] Prabhu, et al., "Physics-based Modeling of Meteor Entry and Breakup," IAA-PDC-15-P-85, 4th IAA Planetary Defense Conference, April 2015

[2] Park and De Rose, "Shape Change of Galileo Probe Models in Free-Flight Tests," NASA TM 81209, 1980.

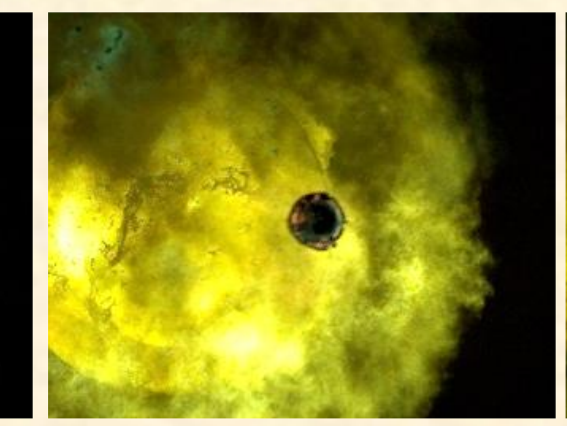
PROJECTILE BREAK-UP IN THE HFFAF

The following image set illustrates the dispersion of fragments from a sphere that was mechanically fractured (unintentionally) by an impact with a thin (25 μm) Mylar diaphragm. Each image is labeled with distance (and flight time) relative to the diaphragm.

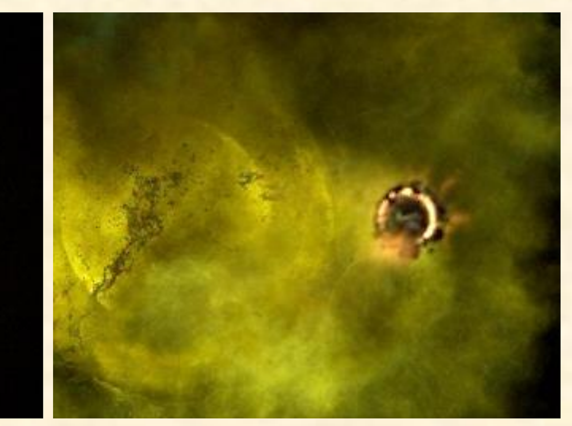
Sphere Diameter: 2.86 cm
Sphere Material: Silicon Nitride
Velocity: 5.89 km/s
Freestream Pressure: 0.016 bar
Stagnation Pressure: 6 bar
Stagnation Heat Flux: 4.8 kW/cm^2



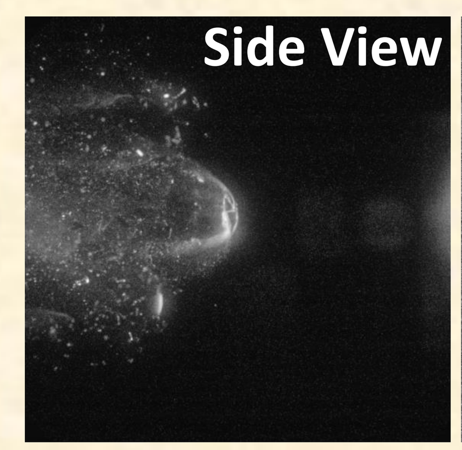
-0.11 m (-0.0196 ms)



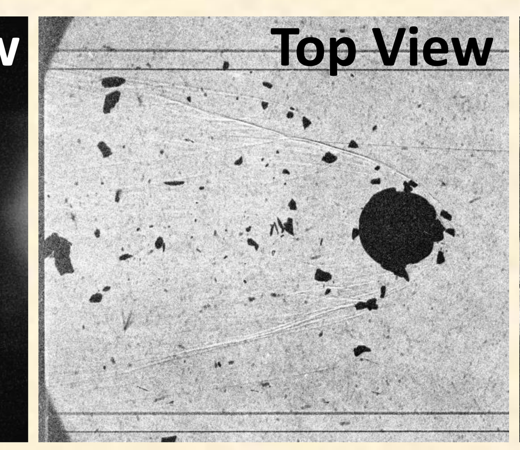
0.69 m (0.12 ms)



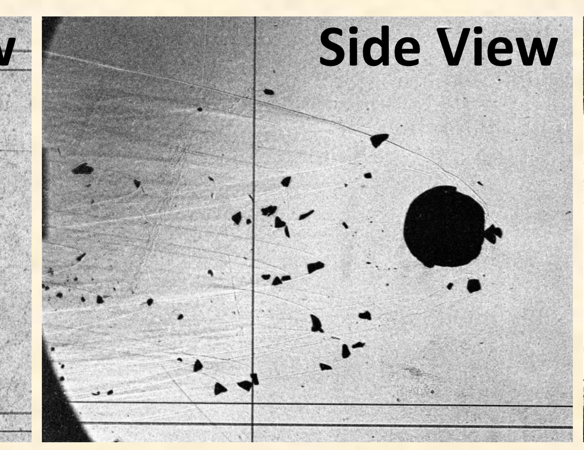
0.92 m (0.16 ms)



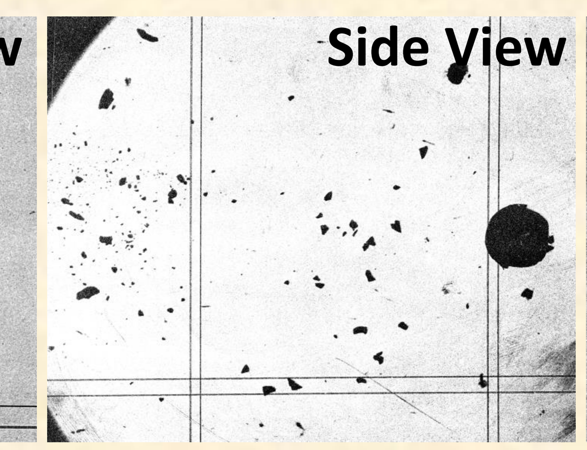
4.9 m (0.89 ms)



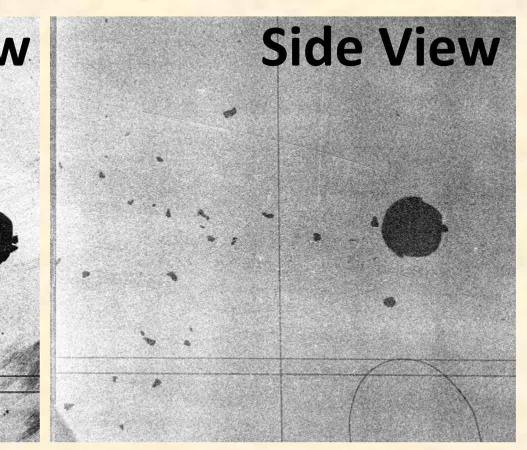
11.0 m (1.94 ms)



14.0 m (2.46 ms)

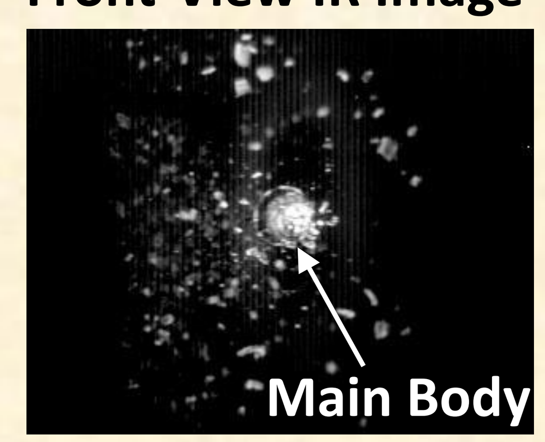


15.6 m (2.72 ms)



18.6 m (3.25 ms)

Front-View IR Image



7.9 m (1.41 ms)

While the fragmentation of this projectile was unintentional, these images illustrate the potential for obtaining experimental data for validating the new entry-breakup simulation tools under development. The potential also exits for launching projectiles designed to deliberately break up in flight. A related facility, the Ames Vertical Gun Range, has successfully launched more comet-like projectiles at speeds approaching 4 km/s, including epoxy-bonded microspheres and Wellman meteorite samples [3].

[3] Tsou, et al., "Intact Capture of Hypervelocity Particles," Lunar and Planetary Inst. Trajectory Determinations and Collection of Micrometeoroids on the Space Station, pp. 85-87, 1986.

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